LEVEL II

A STUDY OF METAL-SEMICONDUCTOR CONTACTS ON INDIUM PHOSPHIDE

University of Minnesota

G.Y. Robinson

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This report describes the research accomplished during the last twelve months of a 20-month program of research on metal contacts to the semiconductor indium phosphide (InP). The Schottky barrier energy ϕ_B and the contact resistance r_c were measured for several metal-InP structures and the electrical properties were correlated to the metallurgical properties obtained with Auger electron spectroscopy (AES). Separate measurement of ϕ_B on both n-type and p-type InP was carried out using Al as the metal (over)

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Electrode. Control samples of Al/GaAs and Al/Si diodes were fabricated simultaneously in order to evaluate fabrication procedures. The Al/InP diodes were rectifying and $\phi_{Bn} < \phi_{Bp}$, in agreement with our earlier work on Pd/InP diodes. Ohmic contacts to p-type InP were also investigated. The results of a study of a multilayered metal film consisting of Au and Be alloyed to the InP surface, are given. It was found that the Au/Be/p-InP structure when properly heat treated would produce ohmic behavior with $r_c = 1 \times 10^{-3} \, \Omega\text{-cm}^2$ at a net doping of about $1.0 \times 10^{17} \text{cm}^{-3}$ and $r_c = 2 \times 10^{-4} \, \Omega\text{-cm}^{-2}$ at $1.4 \times 10^{18} \text{cm}^{-3}$. The Au/Be contact was relatively easy to apply but tight control over the Au/Be thickness ratio and heat-treatment cycle was found to be necessary.

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1. INTRODUCTION

In recent years the use of InP in microwave and optoelectronic applications has produced an interest in the properties of metal-InP contacts. For rectifying Schottky diodes, it is believed that the Schottky barrier energy ϕ_B is lower on n-type InP than on p-type InP (i.e., $\phi_{Bn} < \phi_{Bp}$), although no definitive measurements have appeared in the literature. With regard to ohmic contacts on InP, the development of low-resistance alloyed or sintered contacts is still in its early stages of development with initial results indicating that it is more difficult to form ohmic contacts to p-type than to n-type material.

It was the purpose of this research program to examine in detail the electrical and metallurgical properties of metal contacts to InP. We report here the separate measurement of both ϕ_{Bp} and ϕ_{Bn} for carefully prepared Al/InP diodes. Since ϕ_B is often found to depend on the particular surface preparation technique employed, we have also fabricated, using similar processing steps, control samples of Al Schottky diodes on p- and n-type GaAs and Si.

We also report here the results of a study of the electrical and metallurgical properties of several multilayered metal films used as alloyed ohmic contacts on InP. In particular, a film of Au and Be was used to form an ohmic contact to p-type InP.

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2. SCHOTTKY DIODES ON InP

2.1. Current Status of Metal-InP Contacts

The literature search (see Report RADC-TR-80-108) that was conducted in 1978 in an attempt to screen the literature for all available information on metal contacts to InP, was extended to cover more recent publications. A bibliography of metal contact studies on InP, containing 56 papers, was prepared and is given in Section 5. The sudden increase in the research activity in metal InP contacts during the last three years, appears to be a result of the availability of good quality single-crystal material, the motivation stemming from the potential device applications of InP, and the need to understand the mechanisms of Schottky-barrier and ohmic contact formation on this material. The reader is referred to the papers listed in Section 5 for the details of these studies. Only some of the models proposed for the formation of Schottky barriers will be summarized here briefly, in order to provide background for our research.

W. E. Spicer and his co-workers[31,32,44,45] have studied the formation of Schottky barriers on covalent III-V compounds using a number of elaborate experimental techniques. Based on their results, they propose that Fermi-level pinning at the metal-semiconductor interface is produced by defect states in the semiconductor which are generated by the heat of condensation of the metal atom released as the atom condenses on the crystal surface. They found that the Fermi-level pinning and hence the Schottky-barrier energy was produced with less than one monolayer

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of metal coverage. The position of Fermi level at the surface
was almost independent of the metal and crystal orientation and
was very close to that produced by oxygen. The Fermi level was
"un-pinned" (no states in the band gap) on good quality surfaces
cleaved in ultra-high vacuum prior to metal deposition. Therefore,
the Schottky barrier was produced as direct result of the inter-
action between the metal and the semiconductor, rather than the
semiconductor surface acting alone; hence they rejected the
Bardeen model on the basis of their experimental results.

According to Spicer model, the metal atom goes into a lower
energy state as it condenses on the semiconductor surface
releasing a large amount of energy which breaks some III-V bonds
on the surface and therefore, releases III-V components, pro-
ducing defects at the semiconductor surface. These defects pro-
duce energy levels in the band gap and cause Fermi-level pinning.
They indeed found III-V components in their metal films in sup-
port of their model. Therefore, the usual assumption of a sharp
metal-semiconductor interface appears to be highly unrealistic
for the covalent III-V compound semiconductors.

This "defect" model also appears to be consistent with the
"anion rule" discussed in a paper by McCaldin et al[52]. The anion
rule states that the Schottky-barrier energy for holes on cova-
lent III-V and II-VI compound semiconductors is essentially
determined by the anion of the compound. McCaldin et al show
that on semiconductors containing the same anion, the Schottky-
barrier energy for holes is about the same whereas the barrier
energy for electrons follows the variation in the band-gap energy.

It is also shown in their work that the Schottky barrier for holes varies approximately linearly with the anion electronegativity. Spicer et al[31,32] argue that the "anion rule" is consistent with their "defect" model since "a surface donor (needed to pin a p-type sample) is produced by removing a cation and/or placing an anion on a cation site thus forming a center only containing anions. Thus, the (Fermi-level) pinning will be expected to be determined by the anion". This might be a simplified description of the actual process. Spicer and his co-workers indicate that the "detailed nature of these defects" they propose in their model might be quite complex and requires a considerable amount of future research. Their studies were performed on samples cleaved in-situ in ultra-high vacuum and with very thin metal films. The formation of real Schottky barriers on chemically etched InP surfaces is probably more complex. The reason for the deviation of InP Schottky barriers from the "two-thirds" rule is not yet well understood. Good Schottky contacts on InP surfaces often yield $\phi_{Bp} > \phi_{Bn} = 1/3 \ E_g$.

Williams et al[30-33] observed that metals produce good Schottky barriers on chemically etched surfaces of n-InP but yield ohmic contacts on surfaces that have been cleaved in vacuum and then exposed to high dosages of oxygen, chlorine or air. Williams et al explain these results in terms of a "defect" model very similar to the one proposed by Spicer et al[31,32]. Williams and his co-workers also observed that the noble metals Cu, Ag, and Au form good Schottky barriers while the reactive metals Al, Fe, and Ni yield ohmic contacts on in-situ cleaved surfaces of

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n-InP. They did not observe any simple linear relationship bet-
ween the metal work functions and the Schottky barrier energies
they measured.

Following a theory for Schottky barrier formation proposed by
Andrews and Phillips[53] and Brillson[54,55], Williams plotted the
Schottky-barrier energy as a function of the heat of reaction per
formula unit for the most stable metal-phosphorous compound
formed between the contact metal and the InP. This resulted in a
very simple plot with a rather sharp transition for the barrier
energy centered at the point where the heat of reaction was zero.
This plot suggests that the metals which form compounds with
phosphorous that are significantly more stable than InP (i.e.,
negative heat of reaction) yield ohmic contacts, whereas the con-
tact metals whose phosphides are less stable than InP (i.e.,
positive heat of reaction) form Schottky diodes. This concept
appears to hold for quite a large range of semiconductors, as
discussed by Brillson[54] who gives similar plots for ZnO, ZnS,
CdS, and GaP. Therefore, there are strong indications that the
chemical reactivity of the metal might play a crucial role in the
formation of ohmic and rectifying contacts.

The Schottky-barrier data measured on solvent-cleaned and
wet-etched surfaces of InP appears to be strongly affected by the
particular surface preparation procedure employed. A brief
review of the publications listed in Section 5 will confirm this
observation. It will also reveal that interfaces prepared in
this manner are probably the least well understood interfaces,
despite the fact that the treatment of InP surface with wet

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chemicals is the usual method of surface preparation prior to metal deposition. More research will be necessary before high quality metal contacts can be formed in a controllable and reproducible fashion on InP surfaces treated with wet chemicals.

It seems appropriate to conclude this section with a quotation from Williams, et al[33]: "Further careful studies of a range of metal-semiconductor contacts under accurately controlled conditions are essential, and calculations of the influence of various forms of defects near the interface on the contact behavior are urgently required in order to give an adequate basis to our understanding of the electronic nature of metal-semiconductor contacts."

2.2. Al Schottky Contacts

Aluminum Schottky contacts on both p- and n-type InP, GaAs, and Si wafers have been fabricated and the electrical and metallurgical characterization of the contact structures have been completed. These devices were prepared in order to compare the properties of Al/InP contacts to the Pd/InP contacts described in earlier reports.

The test devices which consisted of an Al film of 90 ± 10 Å thickness on the semiconductors and a 3000 Å-thick Al film for the bonding pads, were fabricated and tested on materials with the same specifications and following essentially the same procedures used in the fabrication of Pd contacts on InP, GaAs and Si which were included in the Report RADC-TR-79-113.

All Al/semiconductor contacts were found to be rectifying and the Schottky-barrier energies (ϕ_B) were measured by current-voltage

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(I-V), capacitance-voltage (C-V) and photoelectric-response (I-E)

techniques. The results are summarized in Tables 2.1 and 2.2.

The values of ϕ_B(I-V) and the diode ideality factor n for the Al

contacts, on InP and Si were not as reproducible as those for the

Pd contacts. ϕ_B (I-V) and n were found to be very reproducible

for both Al/GaAs and Pd/GaAs diodes. ϕ_B (I-V) and ϕ_B (I-E)

measured for the same metal contact agreed reasonably well for

Al/p-InP, Pd/p-InP and Pd/n-GaAs contacts but ϕ_B(I-E) was

slightly greater than ϕ_B(I-V) for the Al/n-GaAs diodes. As

observed previously, ϕ_B (C-V) values were always higher than

either ϕ_B(I-V) or ϕ_B (I-E). This latter result has been observed

in our laboratory for many types of Schottky diodes and by others

as well[56] and it is not well understood at present.

The sum of the independently measured values of $\phi_{B_{no}}$(I-V) and

$\phi_{B_{po}}$(I-V) agreed within experimental error with the accepted

values of the band-gap energy E_g for InP (1.34 $\pm$ 0.01 eV), GaAs

(1.42 $\pm$ 0.01 eV) and Si (1.11 $\pm$ 0.01 eV). A heat treatment cycle

of 5 minutes at 500°C was necessary to stabilize the Al/Si contacts.

All measurements were performed at room temperature. It was

again found that, as in the case of Pd contacts, ϕ_{Bp} (I-V) was

greater than ϕ_{Bn}(I-V) for the Al/InP contacts while the opposite

was found for the Al/GaAs and Al/Si diodes. It was also observed

that ϕ_{Bp} (I-V) on InP was larger for Al as compared to that for

Pd while ϕ_{Bn} (I-V) on InP was smaller for Al than for Pd contacts.

Since Al is more reactive than Pd, this trend is in the same

direction as those observed by Williams et al[6,7] under different

experimental conditions as discussed in the preceding section.

The AES depth-composition profiles of the as-fabricated
Al/semiconductor contacts are presented in Figures 2.1 - 2.3.
As expected on the basis of electrical measurements, all contact
structures were found to contain oxygen at the interface and
throughout the Al film. Carbon was also present at the interface
for most contacts. It could not be determined which processing
step(s), if any, were responsible for the presence of carbon and
oxygen in the Al film. This contamination problem is believed to
be a result of the high chemical reactivity of Al. It should be
mentioned that at this point that no contaminants were detected
in the Pd/semiconductor structures beyond the free surface of the
Pd film of 90 $\pm$ 10 Å thickness. The components of the III-V
compounds appear to be present throughout the Al film as seen in
Figures 2.1 - 2.3. Similar observations were also made on the
AES depth-composition profiles of Pd/semiconductor contacts.
However, the actual extent of this apparent intermixing of metal
and semiconductor components is very difficult to determine since
non-uniform sputtering effects also contribute to the width of the
observed transition region between the metal and the semiconductor.
In any case, the general trend of the intermixing that occurs
during processing can be determined on a relative basis.

2.3 Conclusions

Al and Pd Schottky contacts were fabricated and tested on all
three semiconductors of both types of conductivity under essen-
tially the same experimental conditions. $\phi_{Bp}(I-V) > \phi_{Bn} (I-V)$
was found for both metals on InP while the opposite was true on
GaAs and Si. $\phi_{Bn} (I-V)$ measured on n-InP and n-GaAs were smaller

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for Al than for Pd diodes. The Pd contacts were slightly more reproducible than the Al contacts. The AES depth-composition profiles of the Al and Pd contacts were similar except that oxygen and carbon were present throughout the Al film whereas no contaminants were detected in the Pd/semiconductor structures.

Table 2.1. Schottky diodes of Al

| Diode | I-V | | | | | I-E | |
	ϕBp or ϕBn (meV)	A^* (Amp/cm^2/K^2)	Diode Ideality Factor n	No. of Devices	$\phi Bpo + \phi Bno$ (eV)	ϕBp or ϕBn (meV)	No. of Devices
p-InP	889 ± 11	60	1.17 ± 0.03	18	1.33 ± 0.02	915 ± 25	2
n-InP	372 ± 10	9.8	1.40 ± 0.20	19			
p-GaAs	651 ± 10	74.4	1.08 ± 0.04	16	1.44 ± 0.01	900 ± 30	2
n-GaAs	731 ± 3	8.16	1.06 ± 0.01	18			
p-Si	643 ± 35	32	1.32 ± 0.25	13	1.13 ± 0.05		
n-Si	452 ± 14	112	1.96 ± 0.20	10			
p-Si*	368 ± 6	32	3.50 ± 0.65	4	1.12 ± 0.02		
n-Si*	711 ± 13	112	1.06 ± 0.04	6			

*After H.T. @ 500°C/5 minutes

($\phi B = \phi Bo - \Delta\phi o$ where ϕBo is the asymptotic value of ϕB at zero electric field and $\Delta\phi o$ is the image-force barrier-lowering energy)

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Table 2.2. Schottky diodes of Al

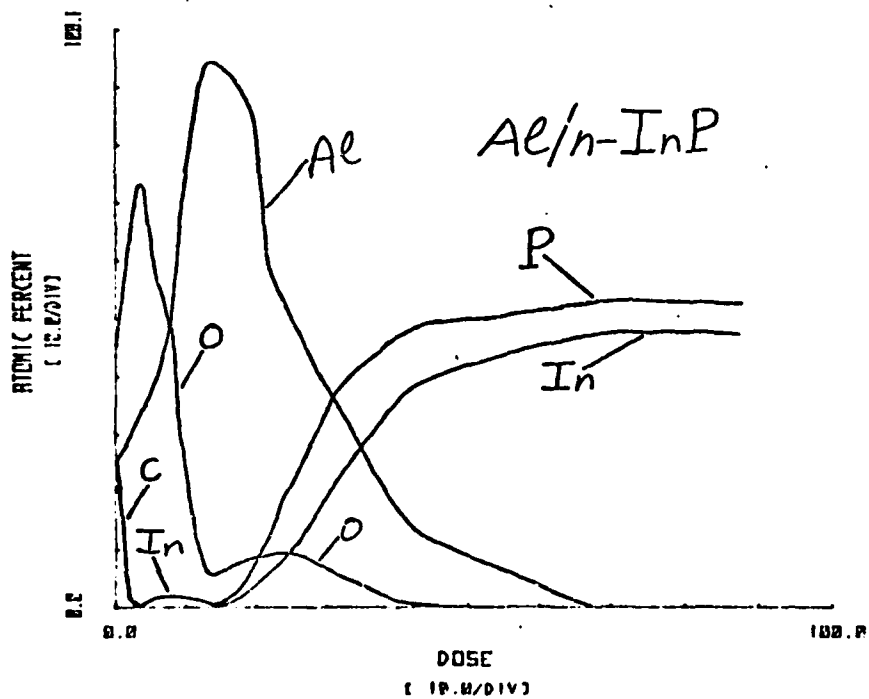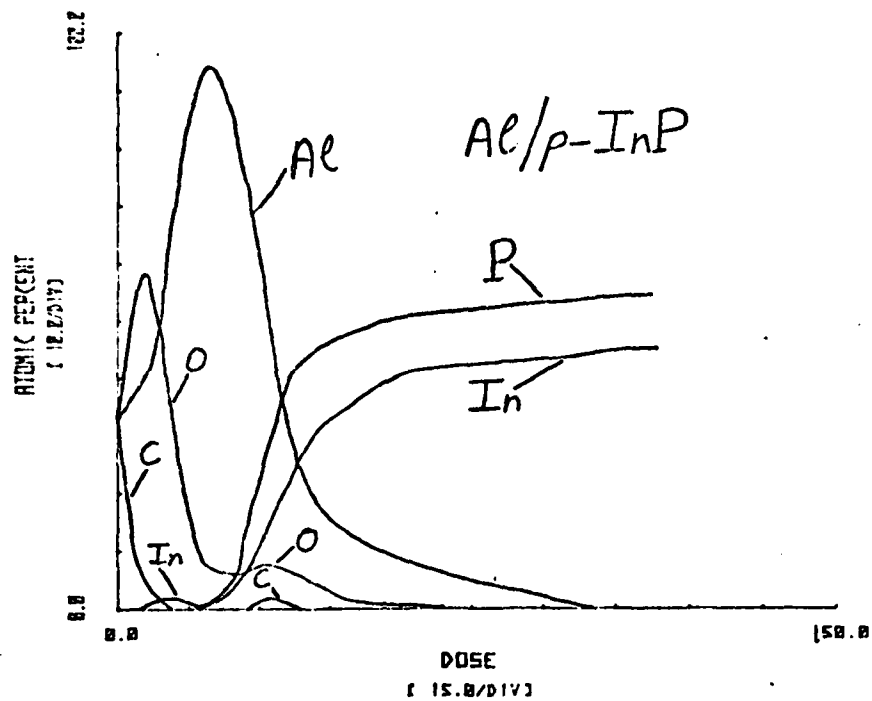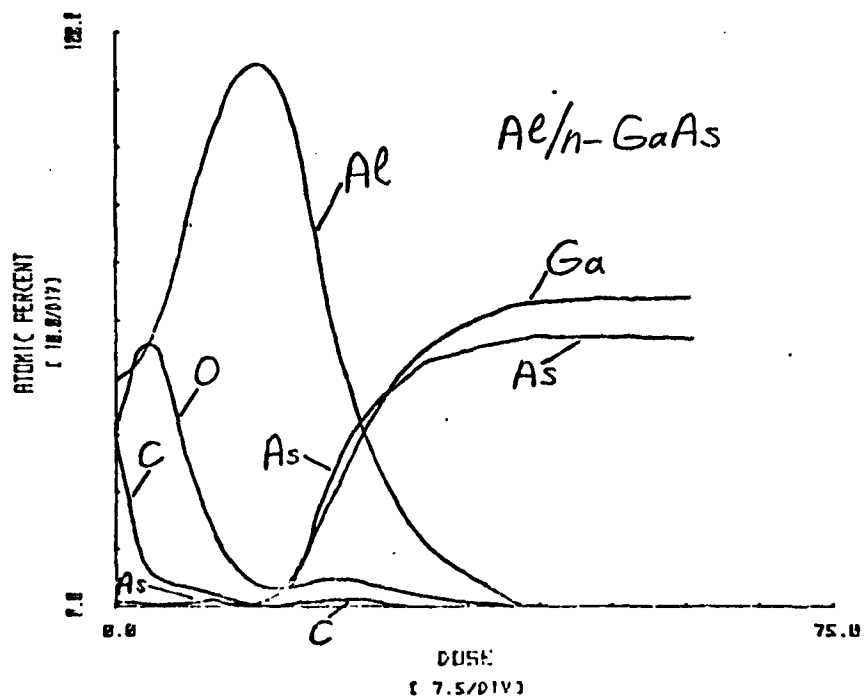| Diode	C-V		
	ϕ_{Bp} or ϕ_{Bn} (meV)	$\lvert N_D - N_A \rvert$ (cm^{-3})	No. of Devices
p-InP	1118 ± 68	2.0 x 10^{17}	5
n-GaAs	832 ± 38	4.9 x 10^{16}	6

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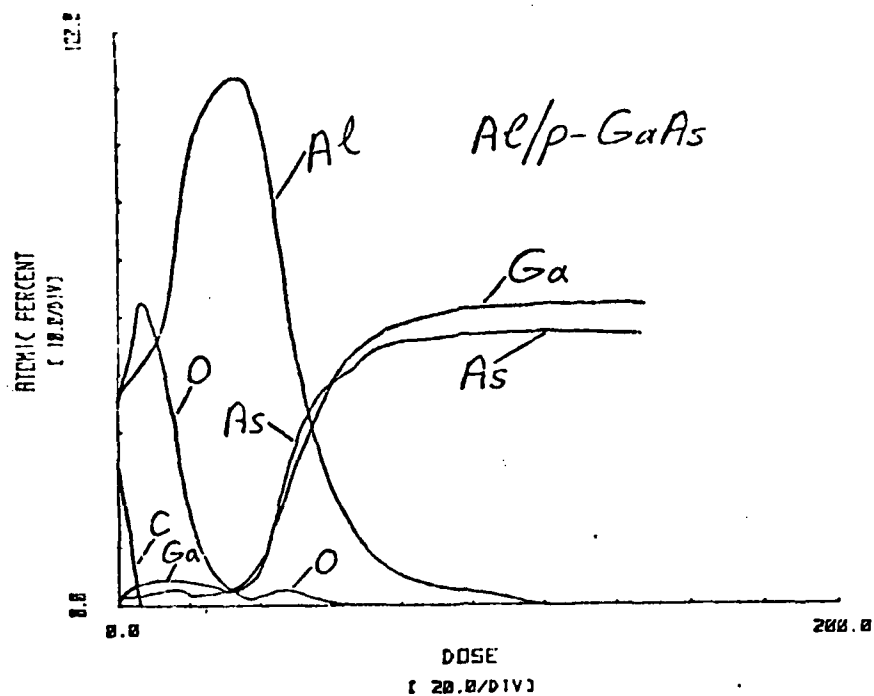Fig. 2.1.   AES depth-composition profiles of Al/InP contacts.

Fig. 2.2. AES depth-composition profiles of Al/GaAs contacts.
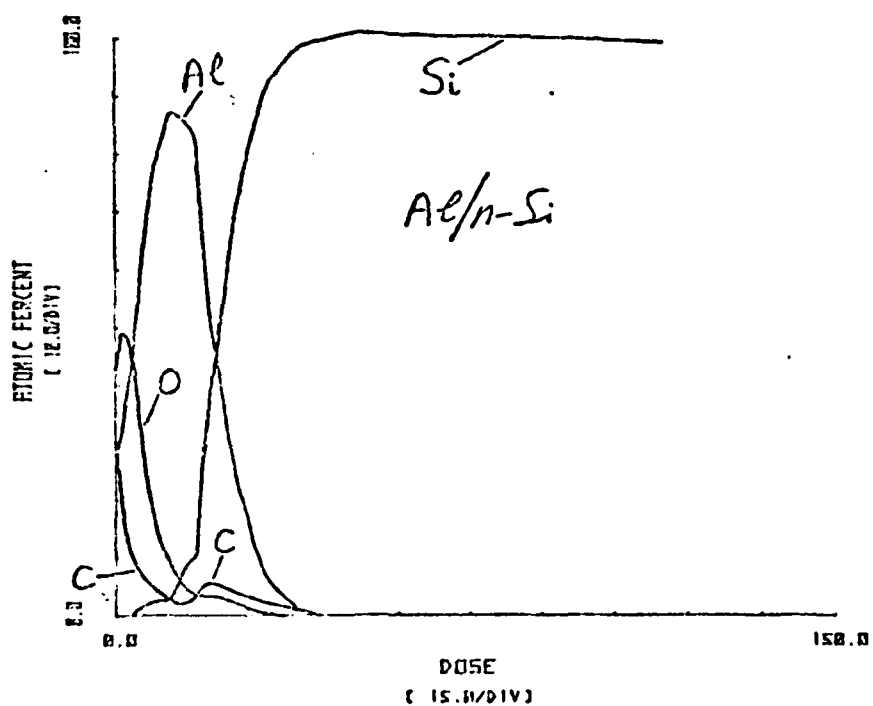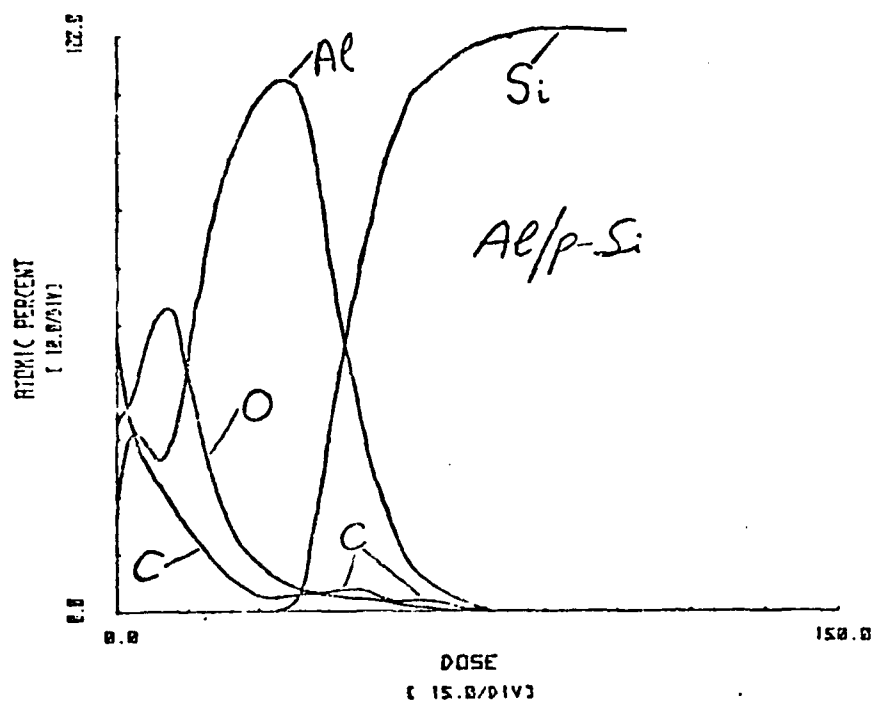
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Fig. 2.3. AES depth-composition profiles of Al/Si contacts.

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3. Au/Be CONTACTS TO P-TYPE InP

3.1. Introduction

A series of alloyed, multi-layered metal films have been examined to determine their suitability for low resistance ohmic contacts to both n-type and p-type InP. Our results are summarized in Table 3.1 where the lowest value obtained for the specific contact resistance r_c is given along with the value of net doping $|N_D-N_A|$ for the InP. As indicated in Table 3.1, it was found that low resistance contacts (i.e., $r_c < 10^{-4}$ Ω-cm^2) to n-type InP could be formed readily; however, it was difficult to achieve low resistance alloy contacts to p-type InP. This is because $\phi_{Bp} > \phi_{Bn}$, as discussed in Section 2.

The best results on p-type InP to date have been obtained with alloyed films containing a mixture of Au and Be. Earlier, we attempted to use Au/Mg contacts and obtained fairly low resistance values, but the surface uniformity and reproducibility was poor. Pd was used in place of the Au, but the contact resistance was too high. In both of these contact structures, Mg was found to oxidize readily during contact fabrication and resulted in the poor reproducibility. More recently we have examined use of Be in place of the Mg and the details of the research on Au/Be contacts is discussed in this section. Air Force reports .RADC-TR-79-113 and RADC-TR-80-108 describe the Au/Mg and Pd/Mg contacts.

In the Au/Be system, Be is chosen as the p-type dopant in order to produce a p$^+$ region in the InP directly under the metal

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(i.e. Au) layer after alloying. Be is easy to vacuum deposit but is highly toxic. Thus the Be source material must be handled carefuly and the vacuum system throughly cleaned after use. Otherwise the Au/Be contact is as easy to apply to the p-type InP as a Au/Ge contact to n-type InP.

3.2. Experimental Procedure

The first set of Au/Be/pInP contacts were formed by vacuum deposition through a shadow mask onto a cleaned and etched InP surface. After heat treatment these contacts became ohmic. Surface adhesion was much better than for Au/Mg.

With these encouraging initial results a second set of contacts employing both front contacts of varying areas and a back contact were fabricated by the method previously described. Briefly, this consisted of forming a back ohmic contact, depositing a layer of CVD SiO_2, etching well defined contact windows in the oxide, and using a liftoff procedure to define the Au/Be pattern. A diffusion-pumped vacuum system with separate resitively heated sources was used to deposit the Au and Be. A predetermined thickness of Be was deposited, immediately followed by a layer of Au without breaking the vacuum. The wafer surface was prepared for metalization by etching[57] with 45% wt. KOH and 10% wt. HIO_3. After metalization the wafers were scribed into individual chips in preparation for separate heat treatments. The heat treatments were carried out in an open tube furnace with a nitrogen atmosphere. The contacts were again examined and the resistance at 10 mV was carefully measured. This resistance data was used to determine r_c after the method of Cox and Strack.[58]

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Two of the bulk p-type InP wafers were provided by the con-
tract monitor and another was purchased from Metal Specialties,
Inc. A description of the wafers used is given in Table 3.2.
Wafers MB 1-3 and AB 10 were fabricated simultaneously.

It should be mentioned that beryllium in any form is extre-
mely toxic[59] and must be handled with great care. The material
should not come in contact with the skin and special care taken
to avoid breathing the dust. No one should attempt to use Be
without first becoming familiar with its toxiology and federal
regulations governing its use.

3.3. Results

In the as-deposited condition all contacts were smooth and
gold colored. The adherance of the metal films was good.
Electrical characterization of the as-deposited contacts included
both I-V and C-V measurements. The results are summarized in
Table 3.3.

The result of heat treatment on the specific resistance of
the contacts for wafer AB 14 is presented in Fig. 3.1. This wafer
had as a minimum value r_c - 1×10^{-3} Ω-cm^2 for a heat treatment
of 3 minutes at 300°C. Ohmic behavior can be seen at tempera-
tures as low as 200°C if the time of this heat treatment is
made long enough.

The appearance of the contacts on wafer AB 14 did not change
for heat treatment up to about 10 min at 400°C. Longer heat
treatments at 400°C results in increasing roughness of the con-
tact surface and a color change from gold to pink. This color
change usually coincided with an increase in resistance. It was

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found that samples whose specific contact resistance was above 10^{-2} Ω-cm^2 no longer had linear I-V characteristics.

Wafers AB 10 and MB 1-3 were simultaneously heat treated and examined. Figures 3.2 and 3.3 show r_c for heat treatments at 300°C, 400°C, and 450°C. On wafer AB 10 the contacts remained rectifying until after heat-treatment at a temperature of 400°C for a minimum time of 10 minutes. The minimum resistance measured was $r_c = 1.0 \times 10^{-3}$ Ω-cm^2 for a heat treatment of 450°C for 3 minutes. A heat treatment of 10 minutes at 450°C resutled in excessive melting of the metal film on the oxide surrounding the contact areas. The scatter in the data for this case was large. Similar results were obtained for sample MB 1-3. As expected however, this sample had lower contact resistance due to its higher doping. The lowest value of r_c measured was 2×10^{-4} Ω-cm^2.

The surface morphology of wafers AB10 and MB1-3 was quite complex. The 300°C heat treatments did not significantly change the surface texture or color. However, heat treatments at or above 400°C for 10 minutes or longer, resulted in changes which were observable with an optical microscope. The contact surfaces became rougher and this area of roughness often included the metal film on the oxide in the vicinity of the contacts. when this happened it was apparent that the reactions in the contact areas were spreading to the bonding pads. In addition to texture changes there were color changes associated with these disturbed regions. At 400°C for 10 minutes the color of the contact areas become predominantly white while the bonding pads remained predominantly gold. The region between the bonding pad and the center

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of the contact, defined by the periphery of the contact where it meets the oxide, had a pink color. This is the same color seen over the entire contact area of samples from wafer AB 14 when similarily heat treated.

This periphery region of the contact also appeared to differ electrically from the central region. For example, Figure 3.4 shows a typical plot of contact resistance versus the reciprocal of the contact area for a sample from wafer AB 14. The slope of the line is r_c. Figure 3.5 shows a typical plot for a contact with the surface morphology just described. This curved line can be explained if the pink region and the white region of the contact have different values of r_c. Preliminary calculations indicate that the pink areas have a value of r_c as much as an order of magnitude larger than the white areas, where r_c is lowest. The curves presented in Figures 3.2 and 3.3 are determined from the larger contacts (i.e. > 10^{-5}cm^2) where this pink region at the contact periphery is a small portion of the total contact area.

Preliminary depth-composition profiles of devices from wafer AB 14 were determined employing Auger electron spectroscopy with ion sputtering. There exists an energy shift in the Auger signal between beryllium when in the metallic form and in the oxide form. To take advantage of this fact the Be Auger peak at 104 eV and the BeO peak at 95 eV were both recorded. However, the energy shift is small enough that there is substantial interference between these two signals. In addition, there is also interference from the P and Au signals. For this reason the

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accuracy of the atomic percent calculations for Be and BeO are subject to question.

Figure 3.6 shows the Auger depth profile of a sample heat treated at 300°C for 3 minutes. To aid clarity, the curves for Be and BeO are shown separately in Figure 3.6b. Despite the large amount of oxygen found at the interface, this contact did yield a very linear I-V characteristic with $r_c = 1 \times 10^{-3}$ Ω-cm^{-2}. This amount of oxygen was typical of that found in the as-deposited contacts.

Shown in Figure 3.7 is the Auger depth profile of a sample heat treated at 400°C for 1000 minutes. There was no observable signal for metallic Be, although a weak signal could not have been detected because of peak interference. The surface of this contact was not smooth but rather had randomly scattered, small hillocks. After the sample was sputtered in the Auger instrument, these hillocks remained visible as small patches of gold color. This would indicate a smearing-out of the Auger profiles, and that some gold may be left on the surface after sputtering.

3.4. Conclusions

The Au/Be ohmic contact appears to be superior to Au/Mg contact in several respects. A reproducable, moderately resistive ohmic behavior is achievable at temperatures below 300°C. Surface adhesion is much better, which may be the reason for the better reproducibility. However, this contact may not be suitable for applications demanding high operating temperatures since additional heating seems to degrade the contact on a lightly doped wafer. The role of each element has not yet been completely

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determined. More Auger data is needed. The great difference in heat-treatment response between wafers AB 10 and AB 14 indicates that the proportions of metals needed to optimize this contact are critical. Finally the use of Au again limits the upper temperatures the contact can be heat-treated at if complete melting of the contact is to be avoided.

Table 3.1. Summary of Ohmic Contacts to InP

Metal Film	Doping $\lvert N_A - N_D \rvert$ (cm^{-3})	r_c $(\Omega - cm^2)$	Surface Uniformity
n-type:			
Ni	3×10^{16}	1×10^{-4}	Fair
Ni/Au/Ge	3×10^{16}	3×10^{-5}	Fair
p-type:			
Au/Mg	6×10^{17}	$\sim 1 \times 10^{-4}$	Poor
Pd/Mg	2×10^{17}	$> 10^{-2}$	Poor
Au/Be	1.7×10^{17}	1×10^{-3}	Good
	1.4×10^{18}	2×10^{-4}	Good

Table 3.2. Wafer Specifications

Wafer	Supplier	Dopant (p type)	Doping given	Doping measured (CV)	Orientation	Au/Be film thickness (A)
MB 1-3	Metal Specialties	Zn	6×10^{17}	1.3×10^{18}	$\langle 111 \rangle$	800/200
AB 10	Air Force	Zn	1×10^{17}	1.5×10^{17}	$\langle 100 \rangle$ 3% off to $\langle 111 \rangle$	800/200
AB 14						900/100

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Table 3.3.   Results for As-Deposited Au/Be on p-InP.

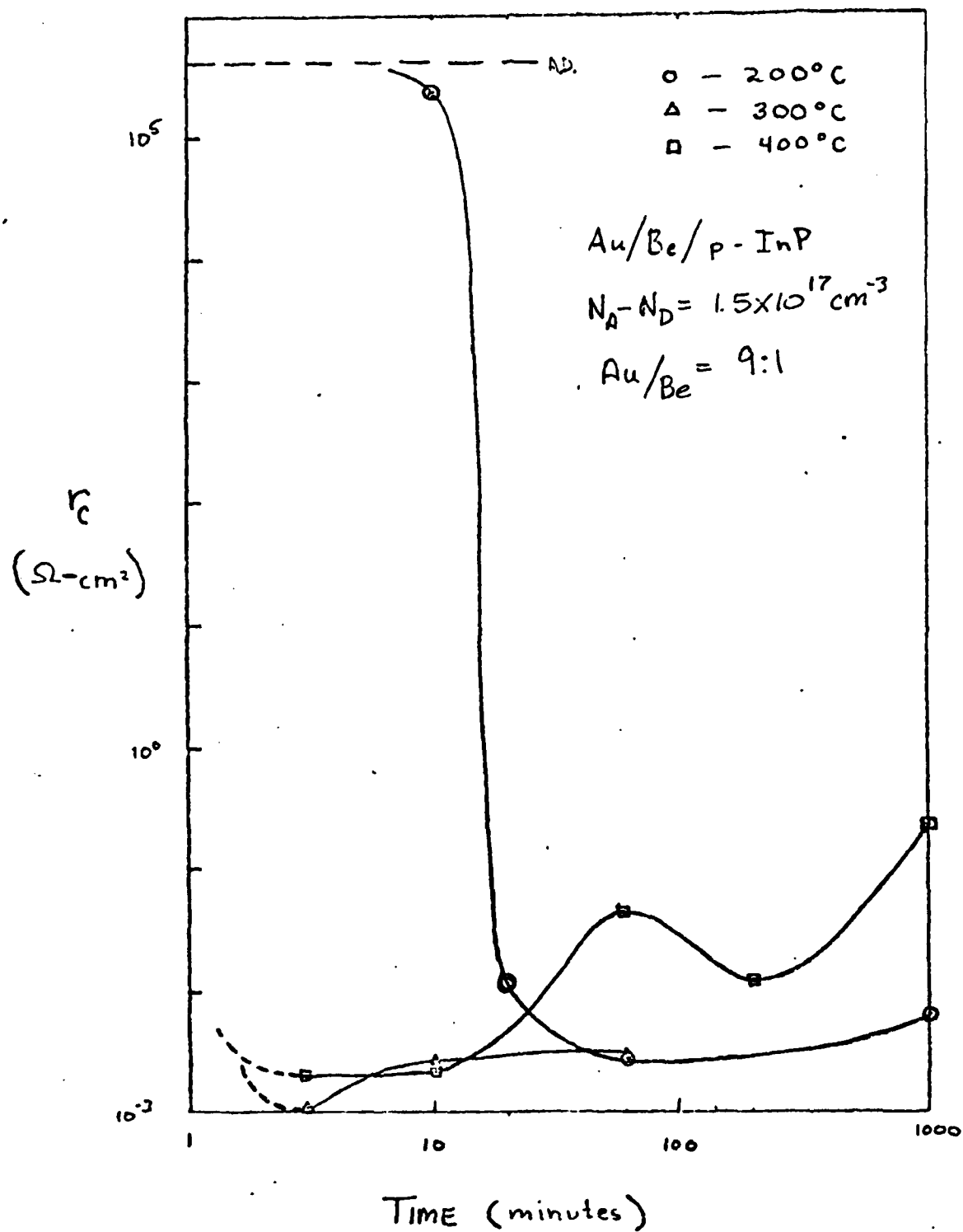| Wafer	I-V		C-V	
	$\phi_B(eV)$	n	ϕ_B (eV)	N_A-N_D (cm-3)
MB 1-3	.78 ± .03	1.3	1.03 ± .03	1.4×10^{18}
AB 10	.75 ± .015	1.15	.87 ± .02	1.4×10^{17}
AB 14	.81 ± .01	1.1	.81 ± .01	1.7×10^{17}

Fig. 3.1. Specific contact resistance r_C as a function of heat-treatment time for wafer AB 14.
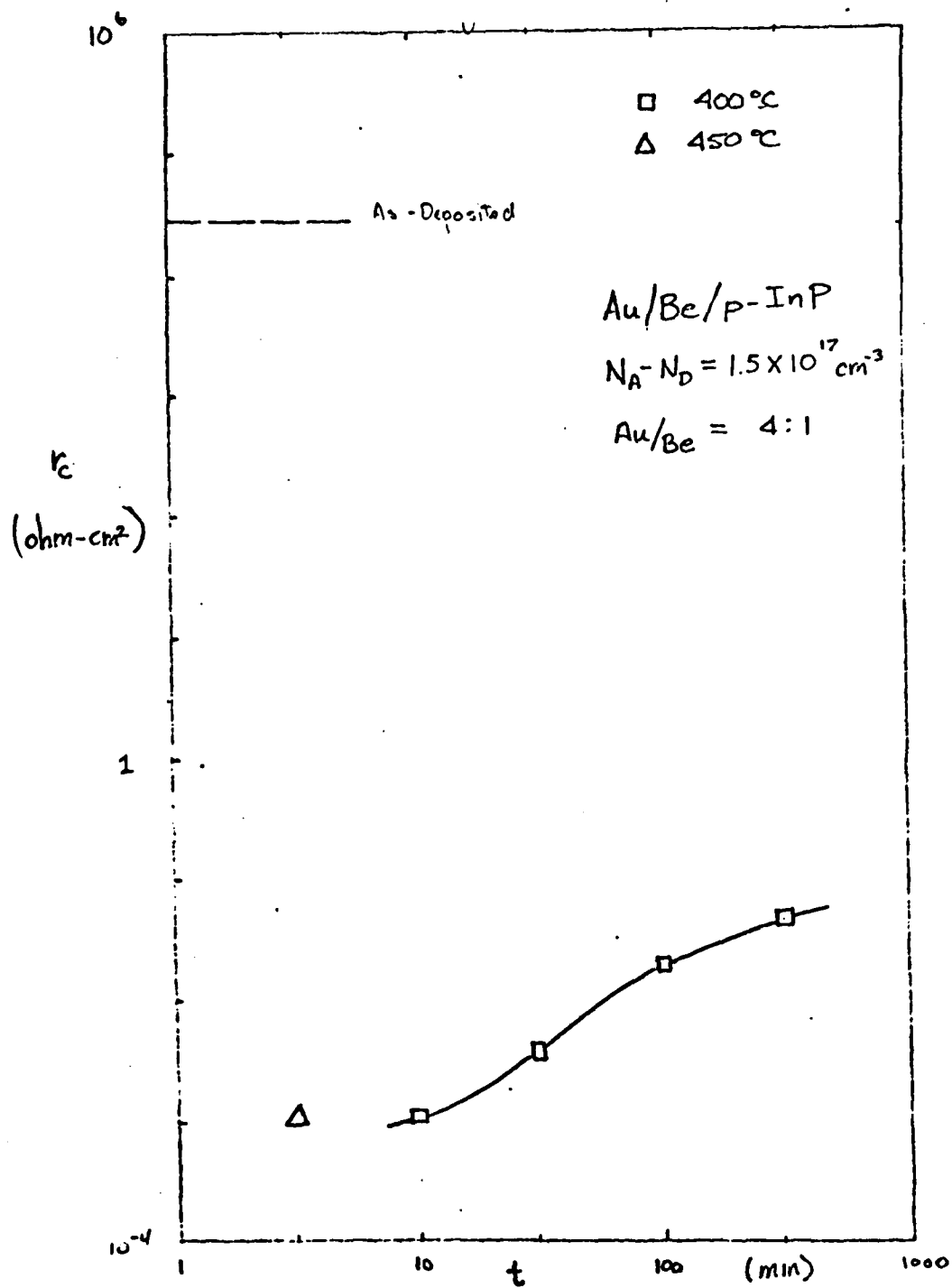
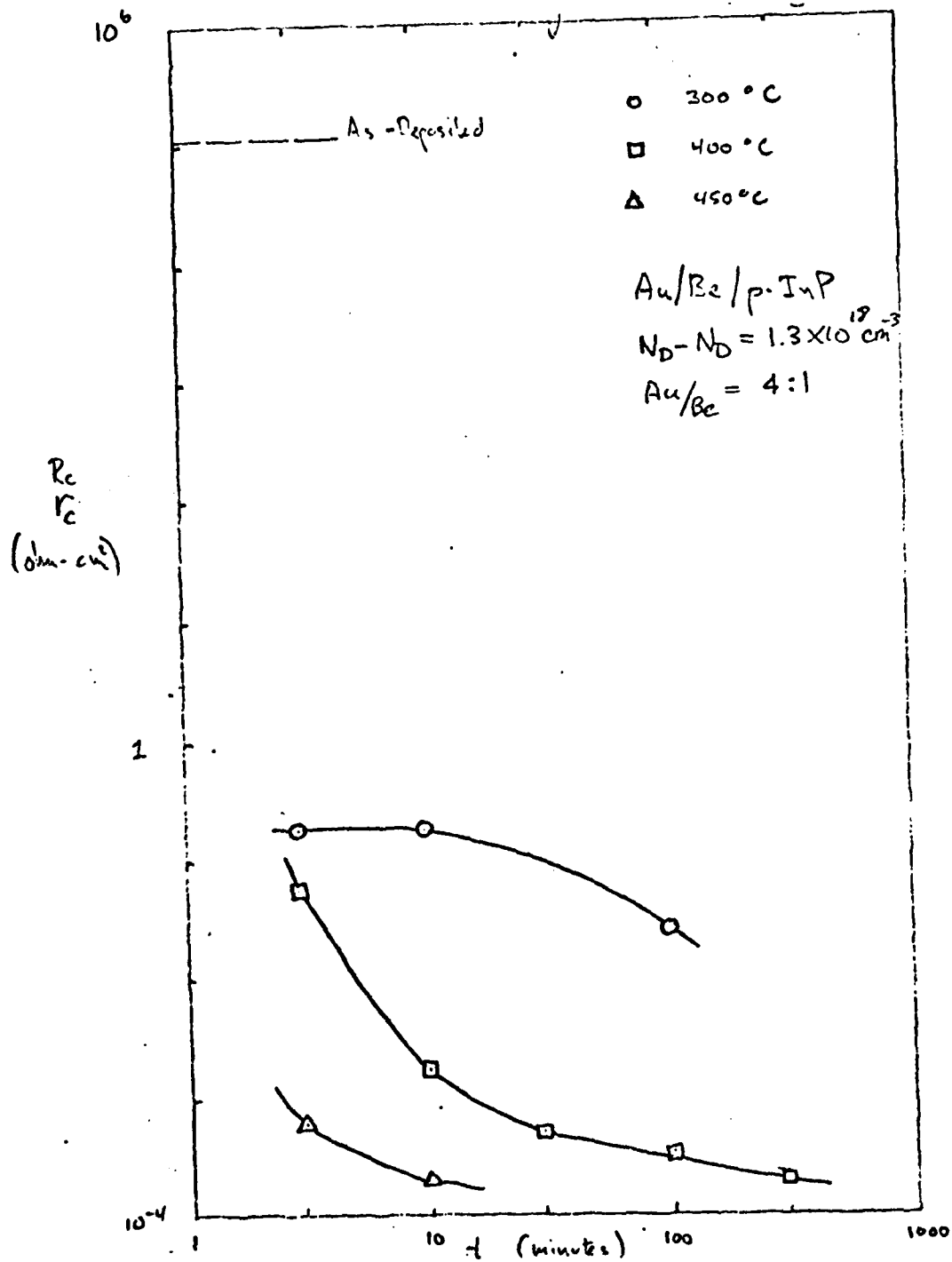Fig. 3.2. Specific contact resistance r_C as a function of heat-treatment time for wafer AB 10.

Fig. 3.3. Specific contact resistance r_c as a function of heat-treatment time for wafer MB 1-3.
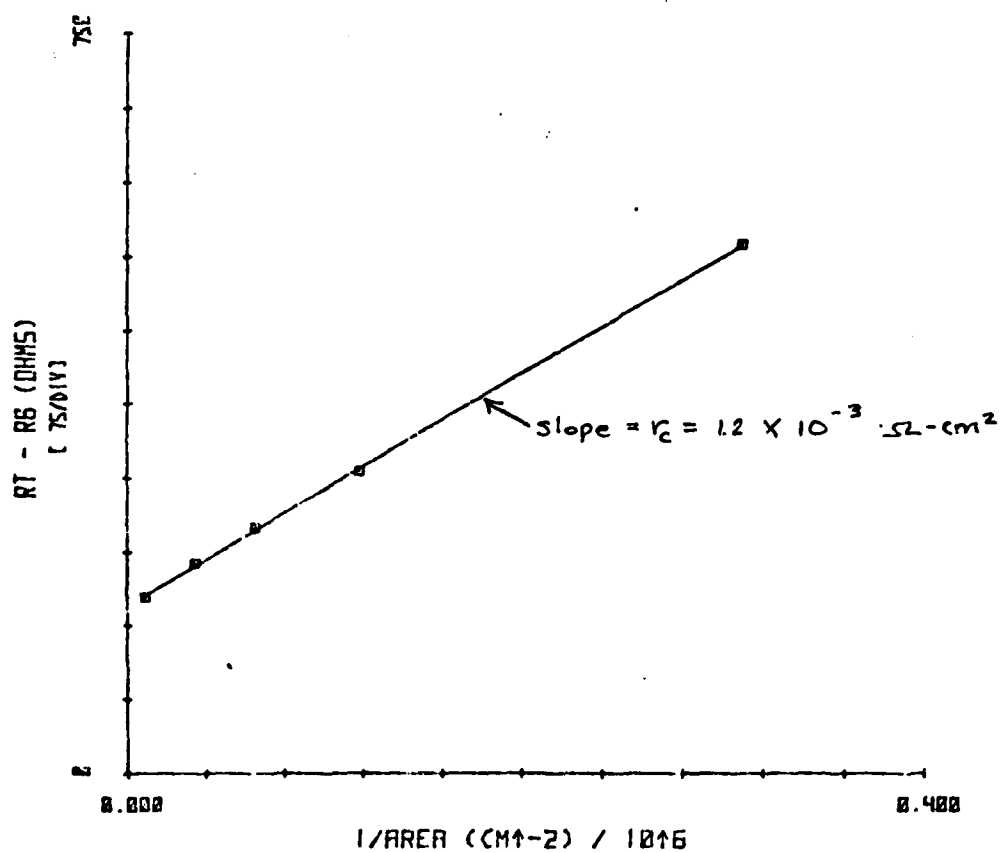
Fig. 3.4. Total contact resistance R_T as a function of the reciprocal of contact area for a typical ohmic sample.

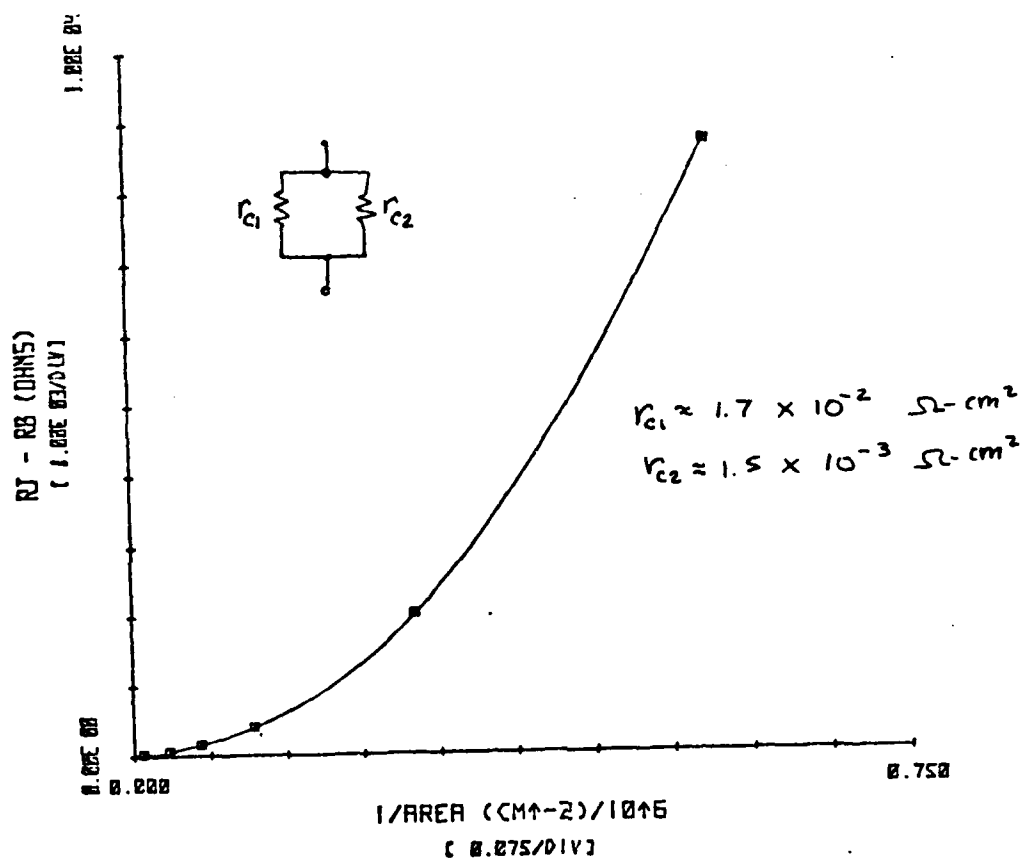Fig. 3.5. Total contact resistance R_T as a function of the reciprocal of contact area for a sample exhibiting a distinct periphery region.
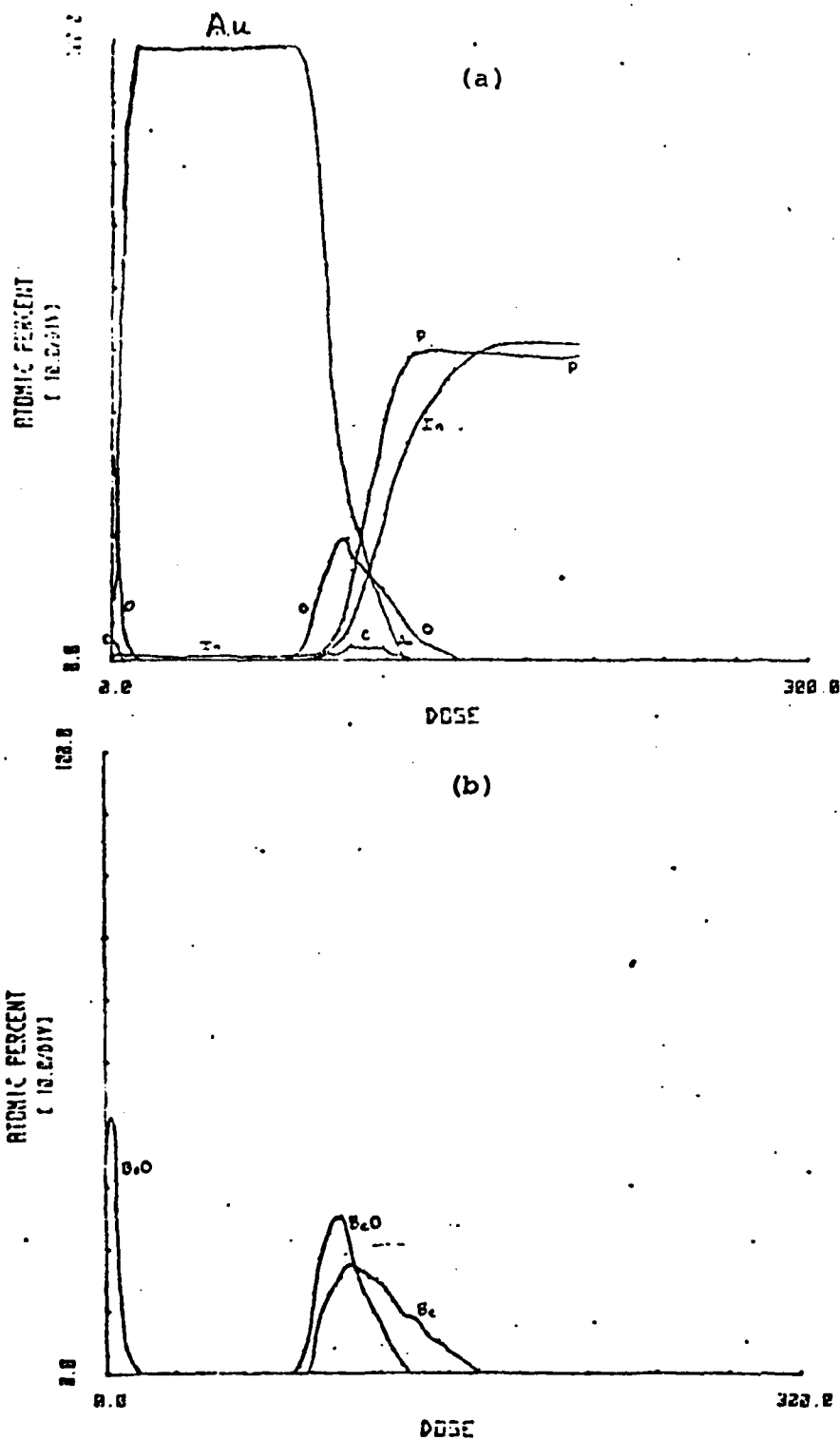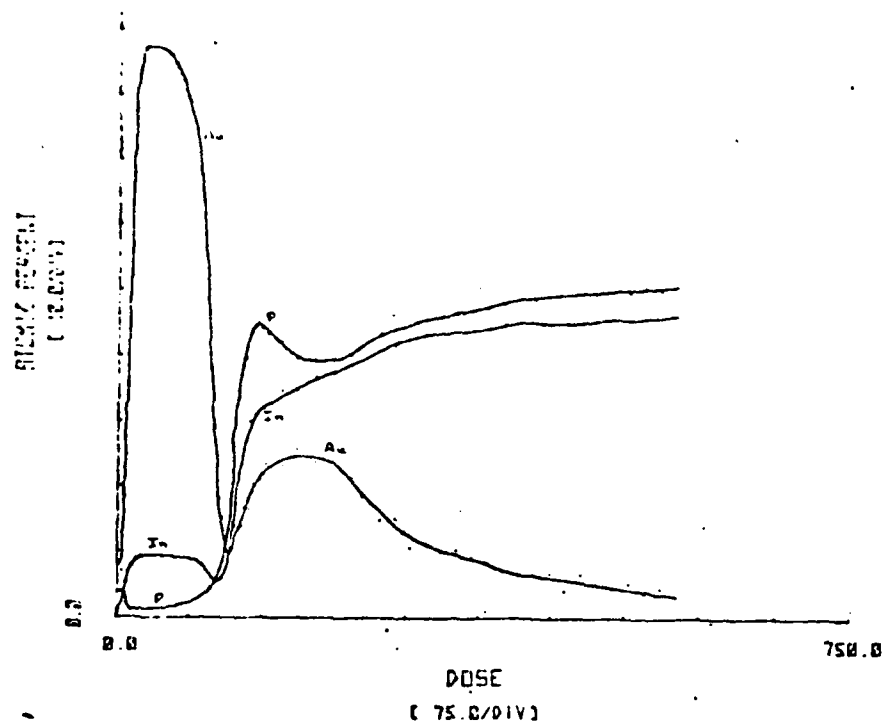
32

Fig. 3.6. Depth-composition profiles obtained with AES and in-situ sputter etching. Sample heat treated at 300°C for 3 minutes.
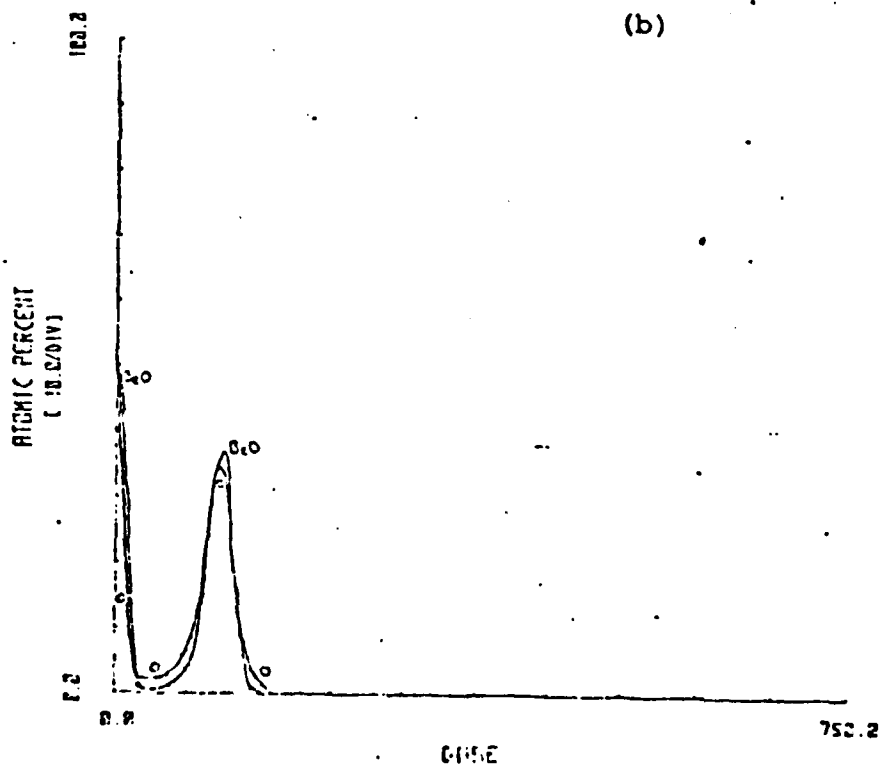
33

Fig. 3.7. Depth-composition profiles obtained with AES and in-situ
sputter etching. Sample heat treated at 400°C for
1000 minutes.

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4. LIST OF PUBLICATIONS

The following scientific papers have been prepared as a result of the research performed under Air Force sponsorship:

1. L. P. Erickson, A. Wasseem, and G. Y. Robinson, "Characterization of Ohmic Contacts to InP", Thin Solid Films 64, 421 (1979). Presented at the International Conference on Metallurgical Coatings, San Diego, April 1979.

2. E. Hökelek and G. Y. Robinson, "A Comparison of Pd Schottky Contacts on InP, GaAs, and Si," Solid-State Electronics, (accepted for publication) 1980.

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